A synopsis on the topic of

Quantum Inspired Evolutionary Algorithms for Image and Video Watermarking

submitted in partial fulfilment of the requirements for the degree of

Doctor of Philosophy

in the area of

Computers and Soft Computing

Submitted by

Pragyesh Kumar

under the supervision of

Prof. C. Patvardhan
(Supervisor)
Dept. of Electrical Engineering,
Faculty of Engineering,
Dayalbagh Educational Institute,
Dayalbagh, Agra

Dr. C. Vasantha Lakshmi
(Co-supervisor)
Dept. of Physics & Computer Science,
Faculty of Science,
Dayalbagh Educational Institute
Dayalbagh, Agra

Dept. of Electrical Engineering, Faculty of Engineering,

Dayalbagh Educational Institute, (Deemed University), Dayalbagh, Agra

September 2014

Introduction to Digital Watermarking

Multimedia has been making our daily life more and more entertainment filled with various electronic and communication mediums. Multimedia contents images-audios-videos separately or in combinations which are now digitized, enhance the quality of the content and reach ability via internet [1]. Digitization improves the creation, modification and transmission of the multimedia contents which are less affected by the noise, but enhances the risk of piracy. Financial losses are tremendous due to unrestricted copies of the media content and quick distribution over the internet.

Cryptography, one of the prominent technologies used by the content owners, encrypts the content with a specified secret key. On purchasing of the content the same is provided to the purchaser. This does not provide any mechanism to prevent the purchaser from further distribution of illegitimate copies of decrypted content. Many copy prevention systems for protection of DVDs and Blue-Ray Discs have been bypassed also.

Thus, an alternative or complement to the cryptography technology is required for the protection of decrypted content against mischievous distribution. Digital watermarking is a strong candidate solution for protection of Intellectual Property Rights (IPR) as it places the information within the content from where it is not possible to remove easily. Removal or destruction of such digital watermark always degrades the quality of multimedia content.

A watermark is a digital code which is embedded into the host data in an imperceptible and robust manner. There is always a trade off between the robustness and imperceptibility of watermark. Watermark usually contains information about the origin or destination of the data, its ownership and copyright related information. Some website links may also be embedded as watermark which provides further link to some relevant information about the digital multimedia content. This cannot provide a direct mechanism for copy-protection of digital multimedia content, but some way for tracking the origin of the multimedia content. A follow up action can then be taken on the basis of information carried by the watermark.

Steganography, another technique which embeds secret information in the host data usually unrelated to the host data allows for covert communication [2]. These methods rely on the assumption that the third party is unaware of the existence of communication. This makes it very low on robustness criteria. Watermark however adds the robustness constraint in such a manner that even if an attacker is aware of existence of embedded information its retrieval and removal is difficult.

Requirements and Benchmarking / Figures of Merit

Watermarking systems can be characterized by various properties. The relative importance of each depends on the final application of the watermark.

1. Integrity with host data: A watermark should be an integral part of the host data. Ideally it should be impossible to remove the watermark from the host data, even by applying signal processing operations on the host data.
2. Ideally Imperceptible: The watermark addition to the host data should not make a perceptible difference to the cover work. This requirement is somewhat conflicting in nature due to the robustness requirement described above and represents the main trade-off in the watermark design.
3. Independent of host data: A watermark should have the inherent capability to become an integral part of the host data but should have its own independent characteristics and quality.
4. Recoverable with the key: There is a security requirement for the watermark which is implemented with the help of cryptographic keys. The necessity of securing the watermark, depending on the implementation, can be two fold. It is possible to secure the detection of the watermark in a given cover work. The keys can also be used to understand the contents of the watermark once it has been detected.
5. Non-degrading: A watermark should not be degradable with transfer over communication mediums or with degradation of quality of content up to a threshold limit.
6. Persistent to Attacks: A watermark should be persistent to several kind of attacks that may possibly be performed either for removal of watermark or degrading the quality of watermark so that it becomes difficult to identify the information it carries.
7. High Payload: The watermark should convey as much information as possible for a particular image size. This is referred to as the *payload*.

A block diagram of a generic watermarking system is shown below:

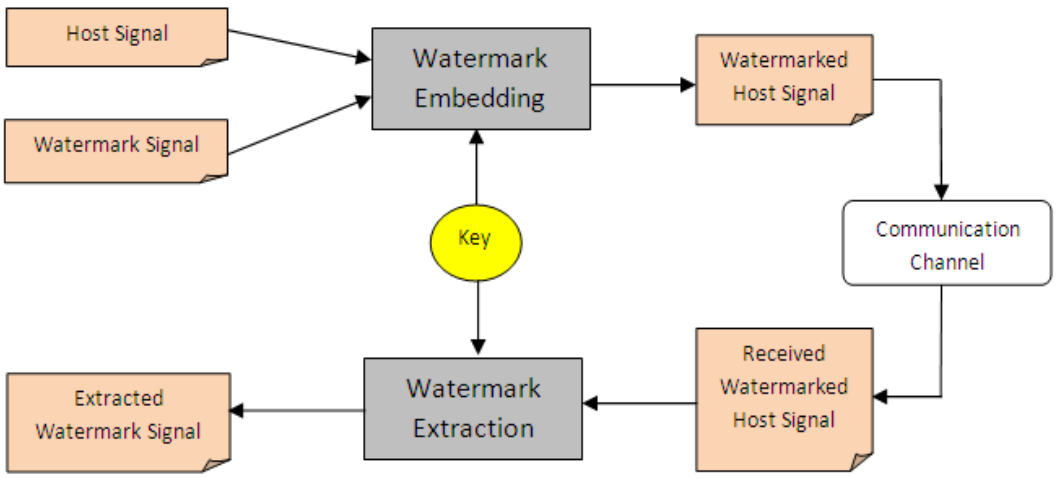

Figure 1: Block diagram of a generic watermarking system

The requirements are better understood by examining as to where in the watermarking system they get applied. For example, the properties associated with the watermarking embedding process are the *payload* and the *fidelity/imperceptibility.* The detection process has other properties associated with it such as *robustness, false-positive behaviour* and *blind* or *informed extraction.* Blind extraction refers to the technique where the original is not required during the watermarking process. In the informed or non-blind extraction the original un-watermarked work is necessary.

Benchmarking

The robustness of the watermark depends on the embedding strength of the watermark. This in turn directly influences the fidelity degradation of the image. It is important to understand the metrics used for evaluating the visual degradation of the image.

The distortion measures used to measure the visual quality are usually *Pixel based metrics* belonging to the group of *difference distortion measures* [3]. Most commonly used measures are the *Signal to Noise Ratio (SNR)* and *Peak Signal to Noise Ratio (PSNR)* which are usually measured in decibels (dB). These distortion metrics are not directly correlated with the human visual system. Hence using these metrics could lead to misleading quantitative distortion measurements.

It would be useful to describe in a bit more detail the conflicting nature of the watermarking requirements. Imperceptibility refers to the ability of the viewer to detect the existence of the watermark. It also describes the quality of the watermarked product by measuring the distortion which is introduced by the watermarking process. An objective measure which is commonly used is the PSNR given by:

$$PSNR = 10 \times \log_{10}\left(\frac{255^2}{\frac{1}{M \times N}\sum_{i=1}^{M}\sum_{j=1}^{N}\left(X(i,j) - X'(i,j)\right)^2}\right)$$

Where $X(i,j)$, is the original image and $X'(i,j)$ is the watermarked image. M and N are the number of rows and columns.

It is clear from this measure that lesser modification would lead to better imperceptibility. However, reducing the number of bits embedded would reduce the pay load of the watermark. For a fixed capacity, embedding bits in the high frequency component would lead to better imperceptibility but in turn would imply lower robustness due to the ease with which high frequency components can be removed with simple filtering operations. Ideally, imperceptibility should be measured using subjective methods as opposed to objective ones as the human visual systems behaves in a manner different from what a measure like PSNR represents.

Bit error rate (BER) a performance criteria has been used to measure the rate at which error occurs during the transmission of watermarked host data. Lower value of BER implies the high quality of transmitted data. It is defined as:

$$BER = \frac{Number\ of\ errors}{Total\ no.of\ bits\ sent}$$

Robustness represents the ability of the watermark to withstand deliberate as well as unintentional attacks. Subjectively the extracted watermark should be similar to the embedded one. Trying to objectively measure this parameter requires the use of the family of correlation functions or others such as the *bit correct rate* with the definition in the equation below.

$$BCR = 1 - \frac{1}{M_W \times N_W} \sum_{i=1}^{M_W} \sum_{j=1}^{N_W} [\, W(i,j) \oplus W^{'}(i,j)]$$

Where $W(i,j)$ is the original watermark and $W^{'}(i,j)$ is the extracted watermark. M_W and N_W is the number of rows and columns.

To make the algorithm robust it is necessary to embed the watermark in the regions where the energy of the host data is concentrated. This is usually the lower frequencies. However, this would sacrifice the imperceptibility as the eye is more sensitive to noise in the lower frequencies than in the higher ones.

Recently, research has been more focused on distortion metrics based on the human visual system (HVS) to exploit properties such as contrast sensitivity and the masking phenomena of the HVS. The computation of the metric is usually more computation intensive. The unity for the metric is defined as units above a threshold which is called the *Just Noticeable Difference (JND).*

Attacks on Watermarking System

Attacks on the watermarking system can be broadly classified into *destruction* attacks and *synchronization* attacks [4]. The destruction attacks seek to damage the embedded watermark. Examples of destruction attacks are the JPEG compression, spatial filtering and image cropping. These do affect the fidelity of the watermarked work however it may be possible to remove the watermark with a minor loss of fidelity. Synchronization attacks such as image rotation or pixel or line deletion focus on removing the ability to detect the watermark. The embedding algorithm would try to extract the watermark information from particular locations in the image. However if these locations are changed with a minor loss of fidelity it would be difficult to extract the embedded watermark.

In terms of performance there are several attacks which can be considered for a particular watermarking algorithm. For any given algorithm the image set used also makes a difference. Stirmark, CERTI MARK, Checkmark, Optimark are some benchmark tests used to test the quality of the watermark [5].

Issues in Still/Video Watermarking

Since the inception of digital watermarking techniques it has been widely used and tested on still images using various types of watermarking techniques in different domains. This establishes some performance evaluation criteria or benchmark on still image watermarking, which has been widely used on various techniques of digital watermarking.

Emergence of video watermarking initially adopted the same techniques that are applied in still image watermarking, considering video as a collection of still images playing at a speed in that a human visual system is not able to identify the separation of still images. The main issues which arise in video watermarking can be listed as follows:

1. Only detection of Watermark: Simplest way to do frame-by-frame watermarking of video content is to extract frames and put the watermark in each frame and again recombine the frames at a specified rate. This technique checks the presence of watermark but does not extract the hidden binary watermark [6].
2. Higher payload: Videos are much larger in size comparison to the image content and, so, are expected to have higher number of bits as payload. Higher payload increases the robustness, but degrades the quality of video.
3. Embedding the same watermark: Same watermark message has been embedded in all of the frames of the video [7]. This technique can easily be attacked with collusion or averaging the frames which in turn remove the watermark from the host video. It also creates artifacts on playing the video.
4. Embedding different watermarks: More improved techniques are used to embed different watermarks in each frame to completely use the available bandwidth [8]. This technique requires higher computation power, which in turn affects the time and cost aspect of the watermarking.
5. Embedding the divided watermark in different frames: This technique uses the same watermark and divide it according to a pre-specified strategy. These divisions are then embedded into a sequence of frames [9]. This strategy fails in case of compression techniques for videos, which generally drop frames from a large number of frames in a video.

Video watermarking has to be robust against all the attacks that are performed on still images described in above section. In addition, video watermarking specific attacks like intentional post processing and hostile attacks are extensively used for corruption or removal of watermark. Intentional processing like spatial and temporal de-synchronization, intentional video editing like effects in between frames, insertion of logos and subtitles leads to quality degradation of the watermark embedded. Frame dropping and averaging of frames from watermarked videos are the most common attacks. Processing time with currently available hardware in embedding the watermark is the most crucial factor in real time watermarking of still and video watermarking.

Issues examined above give rise to concern that still image watermarking techniques do not cover the actual watermarking tasks and fail with some simple attacking strategies. Video watermarking requires to be researched as a separate problem area than the conventional still image watermarking and there is necessity to develop some new and innovative techniques in this regard.

Watermarking Techniques

The various approaches used are broadly classified into spatial and transform domain techniques. The sections below present a few implementations available in the literature.

Spatial Domain Watermarking

Watermarking in the *spatial domain* is also called *additive watermarking*. These types of schemes represent the fundamental schemes which were proposed in the early years of watermarking research. Even though they are simpler to implement they inherently tend to be not robust. Error control codes tend to improve the performance of the watermark slightly.

The watermark is embedded by the alteration of pixel values in the spatial domain. The embedding procedure can be represented as [3]:

$$X'_i = X_i + \alpha_i \cdot W_i$$

Here X_i represents the original value for a pixel and α_i represents the *embedding strength* which controls the extent to which the original value is modified by the watermark W_i. The watermark itself can be permuted using a secret key. This is done so as to spatially disperse the watermark pixels.

Watermark extraction in the spatial domain tends to be some variant of the cross-correlation process between the received image X''_i and the embedded watermark W_i (shown in the equation below) where usually the existence of the watermark is determined.

$$\rho = \frac{\sum_{i=1}^{N} X''_i \cdot W_i}{N}$$

A pre-determined threshold value is defined and if the value is greater than it the watermark is said to be present, else it is not.

Example of a Spatial Domain watermarking scheme

There are several instances where researchers have tried to work with spatial domain watermarks. Here one such method is discussed. This will also be used in later sections to introduce the advantages of certain optimization methods.

The embedding procedure

The least significant bit (LSB) of the pixels determined by set K has been used to embed the watermark information. Nature of modification to a pixel can vary. It is possible to use adaptive histogram manipulation to compress the 8 bits representation of the pixel to 7 bits and then use the spare 1 bit for embedding the watermark bit. Alternatively, the simpler option would be to replace the LSB of the pixel with the watermark bit. The key **K** is usually the seed of a pseudo random sequence generator which determines the positioning of the watermark in the cover image [10]. The watermark itself is an m-sequence which has been used for its good auto and cross correlation properties.

The extraction procedure

The L pixels are extracted according to the key ***K*** and extracted watermark bit $\acute{w_i} = \mathrm{LSB}(\acute{p_i})$. The extracted watermark is $\boldsymbol{W}' = \{\acute{w_1}, \acute{w_2} \ldots \acute{w_L}\}$. This may be used to test for validity with the original watermark using some form of correlation measure.

This method has very good imperceptibility but performs poorly under the robustness tests as it fails simple JPEG compression tests also. This is because JPEG compression involves losses in the high frequency components of the spectrum which is where the watermark gets embedded in this case. Also, it is very simple to attack this watermark as you could randomly flip the bits of the image which would make the watermark disappear.

Transform Domain Watermarking

These represent the more commonly found set of techniques in the research literature. This sub-class of techniques is usually referred to as the *multiplicative techniques* and tend to be more robust as compared to the spatial domain counterparts. The most popular transforms which are encountered are the Discrete Fourier Transform (DFT), Discrete Cosine Transform (DCT) and the Discrete Wavelet Transform (DWT). Multiplicative watermarks are automatically image dependent and are embedded in to the frequency spectrum of the image.

The entire process can be usually divided into three main steps, image transformation, watermark casting and watermark recovery [3]. The multiplicative embedding rule can be represented as:

$$\boldsymbol{X'_i = X_i \cdot (1 + \gamma W_i)}$$

γ being the gain factor.

The watermark detection in this case is again using correlation. For a watermark with length ***L*** this can represented as

$$\boldsymbol{R_{X'',W} = \frac{1}{L}\sum_{i=0}^{L-1} X''_i \cdot W_i}$$

One important fact to note is that while working in the frequency domain it has been a constant matter of debate as to which frequency component should be altered. There have been various suggestions with varying pros and cons to embed in the low, medium or high frequency regions components.

Example of a Transform Domain watermarking scheme

The work done by Cox et al. [11] is one of the classical examples of watermarking in the transform domain. They stress on the fact that a good watermarking system is divided up into two components, the *watermark structure*, and the *insertion strategy*. The watermark structure proposed is to use a Gaussian N(0,1) i.i.d. (independent identically distributed) sequence of real numbers as opposed to creating a simple binary watermark. The *insertion strategy* involves embedding the watermark into the *perceptually significant* regions of the cover image.

Their approach is analogous to spread spectrum communication in which a narrow band signal is spread over a much larger bandwidth so that the contribution of any particular frequency

component is very small. So the watermark is spread over as many frequency bins as possible which means the energy change for any particular bin is almost undetectable.

The DCT transform has been used to convert the image into the transform domain.

The embedding procedure

From the image document *D* a set of values $V = v_1, v_2, v_3 \ldots v_n$ are selected into which the watermark sequence represented by $X = x_1, x_2, x_3 \ldots x_n$ is embedded to get the adjusted set of values *V'*. The addition of the watermark is done using the relation:

$$v'_i = v_i(1 + \alpha x_i)$$

Here α represents a scaling parameter which enables the control of the limit to which the frequency component is modified.

The extraction procedure

The watermark is found by subtracting the corresponding coefficients of the recovered image document and the unmarked copy of the image document. The extracted watermark *X** is unlikely to be identical to the embedded watermark *X*. To detect the watermark a similarity measure given by the equation below has been used.

$$sim(X, X^*) = \frac{X \cdot X^*}{\sqrt{X^* \cdot X^*}}$$

This method of watermarking has shown good performance for a variety of tests which include collusion, JPEG compression, scaling, cropping as well as Printing/Scanning operations. However in their conclusion they discuss the importance of the selection of location for the watermark in the frequency components keeping in mind the imperceptibility criteria. Another avenue of research left open is the study about the degree to which the frequency components can be modified so that the data is embedded in a robust manner but without any visual distortion.

DFT [12] and DCT [13] were used for watermarking in earlier days. The evolution of DWT [14] in spread spectrum domain for various applications gave motivation to use it in watermarking. A comparative analysis of DWT with DFT and DCT is also reported [15], which shows the increased robustness with DWT.

Use of Intelligent Techniques

The basic requirements of watermarking systems are the *robustness* and the *imperceptibility* of the embedded watermark. Both are inherently conflicting in nature. Any solution seeks to find the appropriate balance between the two. Hence, it is as an optimization problem which is where intelligent techniques such as genetic algorithms, neural networks etc. prove to be very useful [16].

Intelligent techniques possess similar qualities as human behaviour [17] as they are able to learn from experience. Their application in the watermarking domain ensures better performance of the existing algorithms. Population-based incremental learning to optimize embedded watermarks [18], dynamic optimization [19], use of biometrics verification fitness during optimization [20], are some of the recent methodologies in intelligent watermarking.

Literature survey for Intelligent Techniques in watermarking

This problem has been approached using intelligent techniques such as Neural Networks and Genetic Algorithms, Ant colony optimization for this purpose. The tables below briefly describe the various approaches used.

Techniques using Neural Networks

Paper Title	Approach used	Claims
Image Watermarking Capacity Analysis using Neural Network **[21]**	Instead of using the communication theory approach for the watermarking problem the authors suggest using a Hopfield Neural Network with Noise Visibility Function (NVF) to analyze the watermarking capacity and the amount of information that can be hidden in the host data.	Watermarking capacity is decided on attraction basin of associative memory of the neural network. Analysis shows maximum numbers of modifiable points are 3650 in a single plane; in five low bit planes points are 18200 for watermarking.
Blind watermarking scheme based on neural network **[22]**	The watermarking technique is based on back propagation neural networks. It takes the HVS characteristics into consideration while embedding the scrambled watermark into the image.	A blind extraction approach using trained neural network can exactly recover the watermark from the image, shows high robustness and good imperceptibility against common image processing attacks on watermarked image.
A Novel Color Image Watermarking Method Based on Genetic Algorithm and Hybrid Neural Networks **[23]**	A new intensity adaptive color image watermarking algorithm based on GA and Hybrid NN using three components sub-images wavelet coefficients from texture-active region.	Improved performance achieved with the use of Hybrid Neural Network, even as Normalized correlation (NC) of the test watermark is lowered up to 0.1628. Trained neural network is able to associate with the original watermark.
Watermarking in Safe Region of frequency domain using complex-valued Neural Network **[24]**	A watermarking scheme based on Complex-Valued Neural Network, CVNN trained by CBP in transform has been used. The complex values obtained by Fast Fourier Transform form the input data of CVNN used to simulate the Safe Region (SR) to embed the watermark mapped to the safe region of selected coefficients.	High level of imperceptibility due to high PSNR up to 76.5250 that has been reported by this watermarking technique, achieved in experimental results.
Performance comparison of watermarking techniques of various domains **[25]**	Techniques based on Back-propagation neural network, Full Counter-propagation neural network and Adaptive resonance theory (ART) have been developed and tested by the author for watermarking.	It shows increased robustness, fidelity and payload capacity of watermarks used in experiment better than the other algorithms taken for comparison.

Techniques using Genetic Algorithms

Paper Title	Approach Used	Claims
Genetic watermarking based on transform-domain techniques **[26]**	An innovative watermarking scheme using GA in transform domain is catering to conflicting requirements to handle watermarking attacks and image quality in consideration.	Increased PSNR and NC values have been obtained with increasing the number of iterations used in GA for watermark test image. For instance PSNR increases from 30.19 dB at 0^{th} iterations to 34.79 dB at 200^{th} iterations.
A new approach for optimization in image watermarking by using genetic algorithms**[27]**	Spread spectrum image watermarking algorithm using the discrete multi-wavelet transform has been used.	Visual quality of watermarked image and robustness of the watermark has been increased, considering optimization of threshold values and the embedding strength as parameters.
Watermarking Robustness Evaluation Based on Perceptual Quality via Genetic Algorithms **[28]**	A benchmarking tool based on genetic algorithms (GA) to assess the robustness of any digital image watermarking system is presented. The main idea is to evaluate robustness in terms of perceptual quality, measured by weighted peak signal-to-noise ratio.	Robustness is preserved in case of low quality threshold (Q=30dB) and attacks. Points out weakness of two well known algorithms and new algorithm able to compare two different kind of watermarking algorithms doing same kind of watermark recovery.
An Adaptive Implementation for DCT-Based Robust Watermarking with Genetic Algorithm **[29]**	Apart from the robustness and the imperceptibility criteria payload is also considered for the optimization using genetic algorithms.	It provides flexible structure in practical implementation as consider the number of bits into for embedding it as watermark.
Image Watermarking based on Genetic Algorithm **[30]**	8x8 DCT in the spread spectrum algorithm using genetic algorithms (GA) to choose the AC coefficients.	GA adaptive global search improved the performance with respect to existing algorithm as high PSNR value of 51 dB is achieved against existing algorithm having a PSNR value of 37.34 dB.
Introducing a watermarking with a multi-objective genetic algorithm **[31]**	Stated as a multi-objective optimization problem (MOP) for the enhancement of digital semi-fragile watermarking based on the manipulation of the image discrete cosine transform (DCT).	Shows simultaneous minimization of distortion and improved robustness criteria. For instance up to 40% of compression of watermarked image NC is having value of 0.9 and also after above than 60^{th} iteration it gives a NC greater than 0.8.
A Novel Color Image Watermarking Method Based on Genetic Algorithm **[32]**	An intensity adaptive color image watermarking algorithm using three channel wavelet coefficients from texture-active region has been used with GA.	Normalized correlation (NC) of the test watermark is 0.3628 and the train neural network is able to associate with original watermark image considered for experiments.
Genetic watermarking based on transform-domain techniques **[33]**	Discrete Cosine Transform based GA watermarking technique, in which GA has been used to train the frequency set for embedding the watermark and image quality of watermark.	GA increases the fitness value with iteration numbers, which improves the watermarked image quality from 30.19 dB to 37.79 dB and the NC values from 0.5300 to 0.7426 for considering LBF attack for instance.
Fidelity-Controlled Robustness Enhancement of Blind Watermarking Schemes Using Evolutionary Computational Techniques **[34]**	Under the condition that fixed amount of watermark bits are hidden, the minimal fidelity requirement of embedded content can be specified by users in advance and guaranteed throughout the embedding procedure.	High watermark extraction rate of about 97% is achieved at 1000^{th} generation, 0.1 mutation rate and a pre-specified PSNR of 40 dB.

Multi-Objective Genetic Algorithm Optimization for Image Watermarking Based on Singular Value Decomposition and Lifting Wavelet Transform **[35]**	Singular value decomposition (SVD) and lifting wavelet transform (LWT) using multi-objective genetic algorithm optimization (MOGAO) has been used. The singular values of the watermark are embedded in a detail subband of host image.	Highest possible robustness has been achieved with maintaining a good quality of watermark transparency using multiple scaling factor (MSF) instead single scaling factor(SSF).
The optimized copyright protection system with genetic watermarking **[36]**	A genetic algorithm for image watermarking is designed with use weighting factors (e.g. λ1 and λ2) in the fitness function. λ1 is associated with robustness whereas λ2 is associate with payload capacity. A variety of combination of weighting factors has been used after 100 GA iterations, with selection rate of 0.5 and mutation rate of 0.1.	Increasing the weight factor value of *λ*1, and λ2 as constant both the resulting PSNR and capacity get decreased. For instance data with weight factor *(λ*1*, λ*2*)* = *(*50*,* 15*)*, *(*100*,* 15*)*, and *(*150*,* 15) taken for consideration.
Intelligent reversible watermarking in integer wavelet domain for medical images **[37]**	An intelligent reversible watermarking approach based on the concept of block-based embedding using genetic algorithm (*GA*) and integer wavelet transform (*IWT*) is proposed for medical images to improve the imperceptibility for a fixed payload.	Improved imperceptibility has been achieved for a desired level of payload (e.g. 0.7) against PSNR value of 40.1 dB.

Techniques using Swarm Intelligence

Paper Title	Approach Used	Claims
A New Approach for Image Watermarking by using Particle Swarm Optimization **[38]**	Human visual system (HVS) and Particle swarm optimization (PSO) with visual secret sharing (VSS) technique to guarantee the security of the procedure.	On test image robustness comparison against JPEG compression attack yields a NC value of 0.9421 on a quality factor (Q=40), 0.9737 on 3*3 Wiener filtering, 0.8706 on 5*5 Median filtering, 0.8934 on 25% cropping attack, better than the compared algorithms in the text.
An intelligent watermarking method based on particle swarm optimization **[39]**	An intelligent watermarking by invoking particle swarm optimization (PSO) technique in wavelet domain by randomly selecting coefficients from different subbands.	Randomly selected coefficients from different subbands are grouped into a block to enhance the transparency, robustness and performance in comparison with the existing algorithms which are not using non PSO methods.
Optimized Watermarking Using Swarm-Based Bacterial Foraging **[20]**	Bacterial foraging has been used to search for the trade-off among requirements and fuzzy theory to design an effective fitness function with the pre-determined requirements.	Fuzzy concept in conjunction with bacterial forging swarm intelligence gives better results to fix the components in the fitness function. For instance fixed weighting factor λ=50 against various attacks yields BCR ranging from 0.7502 to 0.8911 higher than the algorithm using only fuzzy concept only.
Fast intelligent watermarking of heterogeneous image streams through mixture modelling of PSO populations **[40]**	A dynamic particle swarm optimization (DPSO) technique which uses a memory of Gaussian mixture models (GMMs) of solutions in the optimization space.	Decreases the computational requirement against evolutionary computing by up to 97.7% with minor impact on the accuracy for detecting watermarks, considering homogeneous streams of document images.
DCT-Based Robust Watermarking with Swarm Intelligence Concepts **[41]**	Bacterial foraging has been used for obtaining an optimized watermarking algorithm with a properly designed fitness function for the watermarked	Simulation results show an improved performance and effectiveness in extraction of watermark quality for bacterial forging and mutation for fixed weighting factor λ=75

	image quality and the capability for the existence of extracted watermark.	against various attacks yields BCR from 0.7276 to 0.8964 higher than the algorithm only using bacterial forging.

Quantum Inspired Evolutionary Algorithm (QIEA or QEA)

Quantum mechanical computers were proposed in the early 1980s, these computers were shown to be more powerful than classical computers on various specialized problems. Research on merging evolutionary computing and quantum computing has been started since late 1990s.

QIEA is based on the concept of quantum computing, inspired with the idea of quantum computing and it is not a quantum algorithm, but an evolutionary algorithm with a novel approach. It is a novel evolutionary algorithm proposed by Han and Kim [42], called a quantum-inspired evolutionary algorithm (QEA), which is based on the concept and principles of quantum computing such as a quantum bit and superposition of states.

Like the EAs, QIEA is also characterized by the representation of the individual, the evaluation function, and the population dynamics. However, instead of binary, numeric, or symbolic representation, QIEA uses a Q-bit as a probabilistic representation, defined as the smallest unit of information. A Q-bit individual is defined by a string of Q-bits. The Q-bit individual can represent a linear superposition of states (binary solutions) in search space probabilistically; due to this property Q-bit represents a better characteristic of population diversity in comparison to other representations. In QIEA to drive the individuals toward better solutions and eventually toward a single state a Q-gate has been used.

A Q-bit individual represents the linear superposition of all possible states with the same probability manages to represent diverse individuals probabilistically, either 1 or 0 by the Q-gate, the Q-bit individual converges to a single state and the diversity property disappears gradually.

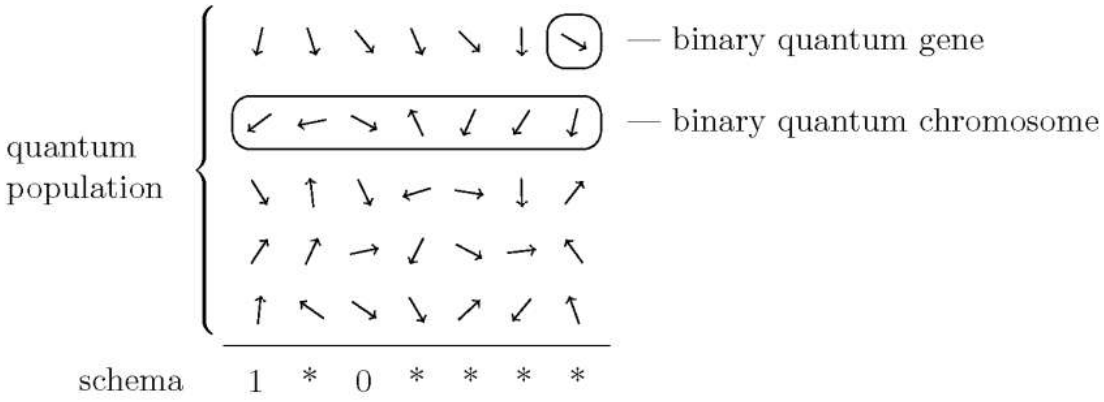

Figure 2: Illustration of binary quantum population. Each arrow represents a state of a quantum gene.

QIEA can treat the balance between exploration and exploitation with this mechanism. The quantum inspired Evolutionary Algorithm given by Han and Kim[42] is described in brief here.

QIEA uses quantum bits (qubits) as the smallest unit of information for representing individuals. Each qubit is represented as $q_i = \begin{bmatrix}\alpha_i \\ \beta_i\end{bmatrix}$ α_i and $\beta_i$are complex numbers representing probabilistic state of qubit so that $|\alpha_i|^2$ is the probability of state being 1 and $|\beta_i|^2$is the probability of state being 0 such that $|\alpha_i|^2 + |\beta_i|^2 = 1$. For QEA α_i and β_i are considered real without losing the generality.

A novel QIEA [40] as follows where Q(t) is the qubit population, P(t) is the population of individual solutions, B(t) is the set of best solutions corresponding to each individuals:

```
Procedure QEA
Begin
    t ← 0
    Initialize Q(t)
    Make P(t) by observing the states of Q(t)
    Repair P(t)
    Evaluate P(t)
    Store the best solutions among P(t) into B(t)
    While ( t<MAX_GEN)
    Begin
        t ← t+1
        Make P(t) by observing the states of Q(t-1)
        Repair P(t)
        Evaluate P(t)
        Update Q(t)
        Store the best solutions among B(t-1) and P(t) into B(t)
        If (migration-period)
            Then migrate b or b_j^t to B(t) globally or locally, respectively.
    End
End
```

In the initialize step the elements of Qubits, $\begin{bmatrix}\alpha\\ \beta\end{bmatrix}$ α, βwere proposed to be initialized to value$1/\sqrt{2}$.

Procedure make is defined as follows:

```
Procedure Make (x)
    Begin
    i ← 0
    While (i < m) do
        Begin
            i ← i + 1
            If (random[0, 1) < |β_i|^2)
                Then x_i ←1
            Else x_i ←0
        End
End
```

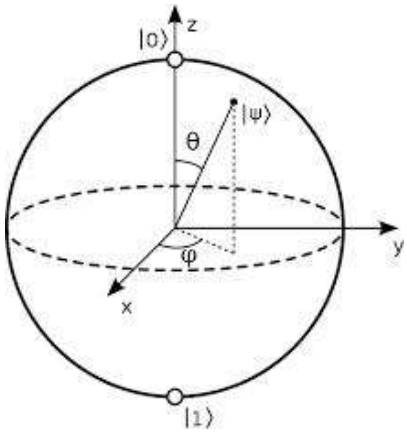

Figure 3: Bloch sphere representation of qubit or quantum bit.

QIEA an effective EA with many potential applications and distinguish features make it very useful in theoretical and engineering research. In engineering many applications in function optimization, face verification, image edge detection, image segmentation, disk allocation, SVM parameter selection, bandwidth adaption, clustering, neural network training, Knapsack problem, etc. The major application areas includes algorithmic implementation of classical problems in computer science, power and energy related issues, optimization problems, soft computing, image processing, economical analysis etc [43].

QIEA is employed in some image processing applications such as image segmentation [44], image edge detection [45], portrait image segmentation [46], image registration [47, 48], they have not yet been employed for intelligent watermarking. This proposed work will attempt to fill this gap.

In comparison to conventional Evolutionary Algorithm, QIEA is having reduced computational complexity due to employing small scale population to solve object problems, can be used for numerical and combinatorial optimization problem, and solves more complex problems than conventional evolutionary algorithms.

QIEA is used in conjunction with swam techniques, colonial algorithms, genetic algorithm, differential evolution, immune algorithms, PSO, neural networks, computational intelligence etc. as hybrid techniques [49].

As QIEA uses the concept of quantum mechanics, which is also in its development phase complete exploitation of quantum computation is still not possible in it. Application of quantum registers, interference, entanglement, etc. in evolutionary algorithm is still an open area of research [43].

Proposed Work

As described above, watermarking of digital images is a thriving research area with intelligent techniques providing a new impetus to the development of ever more powerful techniques. The present work would attempt to carry forward these research endeavors. With the continued development of better Intelligent and Hybrid Techniques that have been used to solve a variety of complex problems in other domains, there is considerable scope for investigation. More specifically, the following are some of the directions that would be pursued in this work.

(i) Some investigations have recently been reported on the use of intelligent techniques for watermarking. This preliminary research has shown that the application of intelligent techniques provides better results than conventional watermarking approaches. This has resulted in a shift in research focus in the area of watermarking from Shannon's theorems to adaptive intelligent techniques and provides motivation for further investigations to improve upon the existing techniques.

(ii) The Evolutionary Algorithms which have been used are fairly simplistic ones in the initial attempts because the emphasis is more on demonstrating their applicability. Thus, there is a lot of scope for improvement using more advanced QIEAs that have better search capability and robustness of performance. Efforts would be made in this direction in this research work.

(iii) Multi-objective algorithmic approaches provide a whole range of solutions to the multi-objective problems in the form of a Pareto Optimal Set. These are particularly suited to the watermarking problem as the problem itself has multiple non-commensurable objectives. Using the more advanced truly multi-objective algorithms could lead to the development of high performance watermarking systems which allow a faster embedding and extraction process with the highest of amount of imperceptibility and robustness.

(iv) Integrated or hybrid intelligent approaches may also be investigated.

(v) From a functional perspective, attempts may be made at building a flexible watermarking framework which would allow for the suitable injection of different binary, greyscale and coloured watermarks.

References

[1] Hartung F., Kutter M., “Multimedia Watermarking Techniques,” in Proc. Of the IEEE, Vol. 87, No. 7, July 1999, pp. 1079-1107.

[2] Cox I. J., Miller M. L., Bloom J. A., Fridrich J., Kalker T., “Digital Watermarking and Steganography”, Second Edition, Elsevier, 2008.

[3] Kutter M., Petitcolas F. A. P., “A fair benchmark for image watermarking system”, Electronic Imaging '99. Security and Watermarking of Multimedia Contents, Vol. 3657, Sans Jose, CA, USA, January 1999.

[4] Pan J.-S., Hunag H.-C., and Jain L. C., “Information Hiding and Applications, Studies in Computational Intelligence”, Vol. 227, Springer Verlag, 2009.

[5] Bi X., Jin G., “Image Segmentation Algorithm based on Quantum Immune Programming”, Proceedings of International Conference on Integration Technology, IEEE, Shenzhen, March 2007, pp. 403-407.

[6] Kalker T., Depovere G., Haitsma J., Maes M., "A video watermarking system for broadcast monitoring. In Security and Watermarking of Multimedia Contents", SPIE Proceedings, Vol. 3657, January 1999, pp. 103-112.

[7] Dittmann J., Stabenau M., Steinmetz R., "Robust MPEG video watermarking technologies", Proceedings of ACM Multimedia, New York, September 1998, pp. 71-80.

[8] Verma A. K., Goyal N., Patvardhan C., "Wavelet Based Robust Video Watermarking Using Spread Spectrum Technique", Fourth International Conference on Computational Intelligence and Communication Networks, IEEE, Mathura, November 2012, pp. 778-782.

[9] Sherekar S., Thakare V. M., Jain S., “Attacks and Countermeasures on Digital Watermarks: Classification, Implications, Benchmarks”, International Journal of Computer Science and Applications, Vol. 4, Issue 2, June-July 2011, pp. 58-64.

[10] Ganic E., Dexter S. D., Eskicioglu, “Embedding Multiple Watermarks in the DFT domain using low and high frequency bands”, Proceedings of SPIE, Security, Steganography and watermarking of multimedia Contents VII, March 2005, Vol. 5681, pp. 175-184.

[11] Cox I., Kilian J., Leighton T., Shamoon T., “Secure spread spectrum watermarking for images, audio and video,” IEEE Int. Conf. On Image Processing (ICIP 96), Lausanne, Switzerland, Sept. 1996, pp. 243-246.

[12] Cox I. J., Lilian J., Leighton F. T., Shammon T., “Secure Spread Spectrum Watermarking for Multimedia”, IEEE Transactions on Image Processing, Vol. 6, Issue 12, December 1997, pp. 1673-1687.

[13] Serdean C. V., Tomlinson M., Wade J. G., Ambroze M. A., “Protecting Intellectual Rights: Digital WM in the Wavelet Domain”, IEEE Proceedings on Trends and Recent Achievements in Information Technology, C Cluj-Napoca, Romania, May 2002, pp. 79-90.

[14] Woo C. S., Du J., Pham B., “Performance Factors Analysis of a Wavelet-based Watermarking Method”, Proceedings of 3rd Australian Information Security Workshop, New Castle, Vol. 44, 2005, pp. 89-97.

[15] Barni M., Bartolini F., Caldelli R., Rosa A.D., Piva.A., "A robust watermarking approach for raw video", Proceedings 10th International Packet Video Workshop PV2000, Cagliari, Italy, May 1-2, 2000.

[16] Wang F.-H., Pan J.-S., Jain L. C., “Innovations in Digital Watermarking Techniques, Studies in Computational Intelligence”, Vol. 232, Springer Verlag, 2009.

[17] Pan J.-S., Huang H.-C., Jain L. C., “Intelligent Watermarking Techniques (Innovative Intelligence)”, World Scientific Press, 2004.

[18] Naheed T., Usman L., “Intelligent Watermarking of Document Images as a Dynamic Optimization Problem”, IEEE International Conference on Information Science, Signal Processing and their Applications” (ISSPA), Montreal, July 2012, pp. 139-142.

[19] Rabil B.S., Sabourin R., Granger E., "Impact of watermarking on offline signature verification in intelligent bio-watermarking systems", IEEE Workshop on Computational Intelligence in Biometrics and Identity Management, Paris, April 2011, pp. 13-20.

[20] Huang H.-C., Chen Y.-H., Abraham A., “Optimized Watermarking Using Swarm-Based Bacterial Foraging,” Journal of Information Hiding and Multimedia Signal Processing, Vol. 1, Number 1, January 2010, pp. 51-57.

[21] Zhang F., Zhang H., “Image Watermarking Capacity Analysis using Neural Network,” IEEE Proceedings of IEEE International Conference on Web Intelligence, Washington, September 2004, pp. 461-464.

[22] H. Song, Zhang W., Feng W., Yang H., “Blind watermarking scheme based on neural network,” in 7th World Congress on Intelligent Control and Automation, Chongqing , June 2008, pp. 5985 – 5989.

[23] Lu Y., Han J., Kong J., Yang Y., Hou G., “A Novel Color Image Watermarking Method Based on Genetic Algorithm and Hybrid Neural Networks”, in Rough Sets and Current Trends in Computing, Lecture Notes in Computer Science, Vol. 4259, Springer Berlin / Heidelberg, November 2006, pp. 806-814.

[24] Olanrewaju R.F., Khalifa O. O., Abdalla A. H., Aburas A. A., Zeki A. M., “Watermarking in Safe Region of frequency domain using complex-valued Neural Network,” International Conference on Computer and Communication Engineering (ICCCE),Kuala Lumpur, May 2010, pp. 1-7.

[25] Bansal A., Bhadauria S.S., Gupta R., “Performance comparison of watermarking techniques of various domains” in 3rd IEEE International Conference on Digital Ecosystems and Technologies, Istanbul, 1-3 June 2009, pp. 1-3.

[26] Shieh C.-S., Huang H.-C., Wang F.-H., Pan J.-S., “Genetic watermarking based on transform-domain techniques” in Pattern Recognition, Vol. 37, Issue 3, Elsevier Science, March 2004, pp. 555-565.

[27] Kumsawat P., Attakitmongcol K., Srikaew A., “A new approach for optimization in image watermarking by using genetic algorithms,” in Vol. 53, Issue 12, IEEE Transactions on Signal Processing, December 2005, pp. 4707-4719.

[28] Boato G., Conotter V., De Natale F.G.B., Fontanari C., “Watermarking Robustness Evaluation Based on Perceptual Quality via Genetic Algorithms,” in Vol. 4, Issue 2, Journal IEEE Transactions on Information Forensics and Security, June 2009, pp. 207-216.

[29] Chu C.-M., Huang H.-C. and Pan J.-S., “An Adaptive Implementation for DCT-Based Robust Watermarking with Genetic Algorithm”, in 3rd International Conference on Innovative Computing Information and Control, Dalian, China, June 2008, pp. 18.

[30] Wei Z., Li H., Dai J., Wang S., "Image Watermarking based on Genetic Algorithm," in IEEE International Conference on Multimedia and Expo, July 2006, Toronto, pp. 1117-1120.

[31] Díaz D. S., Romay M. G., “Introducing a watermarking with a multi-objective genetic algorithm”, Conference on Genetic and evolutionary computation, Washington DC , USA, June 2005, pp. 2219-2220.

[32] Lu Y., Han J., Kong J., Hou G., Wang W., “A Novel Color Image Watermarking Method Based on Genetic Algorithm”, Intelligent Computing in Signal Processing and Pattern Recognition, Springer Berlin / Heidelberg, Vol. 345, August 2006, pp. 72-80.

[33] Shieha C.-S., Huangb H.-C., Wangc F.-H., Pana J.-S., "Genetic watermarking based on transform-domain techniques", Elsevier-Pattern Recognition, Vol. 37, Issue 3, March 2004, pp. 555-565.

[34] Huang C.-H., Shen C.-H., Wu J.-L., “Fidelity-Controlled Robustness Enhancement of Blind Watermarking Schemes Using Evolutionary Computational Techniques,” in Digital Watermarking, Lecture Notes in Computer Science, Vol. 3304, Springer Berlin / Heidelberg, 2005, pp. 271-282.

[35] Loukhaoukha K., Chouinard J.-Y., Taieb M. H., “Multi-Objective Genetic Algorithm Optimization for Image Watermarking Based on Singular Value Decomposition and Lifting Wavelet Transform,” in Image and Signal Processing, Lecture Notes in Computer Science, Vol.: 6134, Springer Berlin / Heidelberg, 2010, pp. 394-403.

[36] Huang H.-C., Chu C.-M., Pan J.-S., “The optimized copyright protection system with genetic watermarking,” in Soft Computing - A Fusion of Foundations, Methodologies and Applications, Vol. 13, Springer Berlin / Heidelberg, 2009, pp. 333-343.

[37] Arsalan M., Malik S. A., Khan A., "Intelligent reversible watermarking in integer wavelet domain for medical images", Elsevier Journal of Systems and Software, Vol. 85, Issue 4, April 2012, pp. 883–894.

[38] Vahedi E., Lucas C., Zoroofi R. A., Shiva M., "A New Approach for Image Watermarking by using Particle Swarm Optimization," in IEEE International Conference on Signal Processing and Communications, 24-27 Nov. 2007, pp. 1383-1386.

[39] Wanga Y.-R., Linb W.-H., Yangc L., "An intelligent watermarking method based on particle swarm optimization", in Expert Systems with Applications, Vol. 38, Issue 7, Elsevier Science, July 2011, pp. 8024-8029.

[40] Vellasques E., Sabourin R., Granger E.,"Fast intelligent watermarking of heterogeneous image streams through mixture modelling of PSO populations," Elsevier Journal of Applied Soft Computing Vol. 13, Issue 6, June 2013, pp. 3130–3148.

[41] Huang H.-C., Chen Y.-H., Lin G.-Y., "DCT-Based Robust Watermarking with Swarm Intelligence Concepts," Fifth International Conference on Information Assurance and Security, vol. 1, 2009, pp.464-467.

[42] Han K. H., Kim J. H., "Quantum-inspired Evolutionary Algorithm for a Class of Combinatorial Optimization," IEEE Transactions on Evolutionary Computation, Vol. 6, No. 6, December 2002, pp. 580-593.

[43] Zhang G., "Quantum-inspired evolutionary algorithms: a survey and empirical study," Springer Journal of Heuristics, Vol. 17, Issue 3 , June 2011, pp. 303-351.

[44] Li Y., Zhang Y. N., Zhao R. C., Jiao L. C.," An edge detector based on parallel quantum-inspired evolutionary algorithm" Proceedings of International Conference on Machine Learning and Cybernetics, IEEE, August 2004, pp. 4062-4066.

[45] Liu H., Zhang D., Yan J. Q., Li Z. S., "Fast and robust portrait segmentation using QEA and histogram peak distribution methods", Lecture Notes in Computer Science, Vol. 3645, Aug 2005, pp. 920-928

[46] Talbi H., Batouche M., Dara A. "A quantum-inspired genetic algorithm for multi-source affine image registration", Lecture Notes in Computer Science, Vol. 3211, 2004, pp. 147-154.

[47] Talbi H., Dara A., Batcouche M.,"A genetic quantum algorithm for image registration", Proceeding of International Conference on Information and Communication Technologies: From Theory to Applications, April 2004, pp. 395-396.

[48] Manju A., Nigam M. J., "Applications of quantum inspired computational intelligence: a survey", Artificial Intelligence Review, Vol. 42, Issue 1, Springer Netherlands, June 2012, pp. 79-156.